

Episode 109: Electrical characteristics

In this episode, students measure the current and voltage characteristics for several components, and identify ohmic and non-ohmic behaviour.

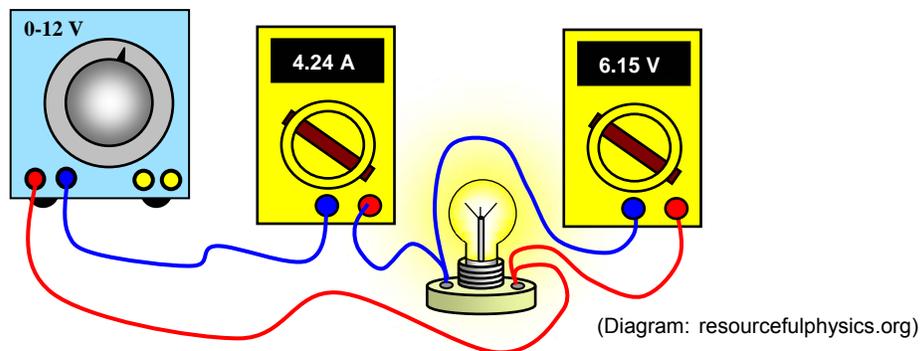
Summary

Student experiment: Further characteristics. (40 minutes)

Student experiment – Alternative version: Further characteristics. (40 minutes)

Discussion: The results. (10 minutes)

Student questions: On characteristics. (30 minutes)



Student experiment:

Further characteristics

Students determine the V-I characteristics for a carbon resistor, semiconductor diode and filament lamp.

This activity is best carried out individually (if space and apparatus allows this) so that each student has to construct and test his/her own circuit. One of the dangers of always working in pairs is that some students who lack confidence in circuit building will always avoid having to do it. This activity gives good practice in building testing and using a circuit designed to measure current and voltage.

They will need a reasonable amount of time to set up, check the circuit and begin to take readings. Make sure they all have correct circuits and that their meters are set to appropriate ranges (many take a long time to come to terms with multimeters). I would suggest about 40 min on the practical work itself. This should allow them all to collect data for all three components.

Some will work much faster than this so it may be worth having some additional activities available (e.g. the characteristic for thermistor).

Data collection can be handled in two ways: Simply record the data into a prepared table, or record directly into Excel or a similar spreadsheet package.

TAP 109-1: Electrical characteristics

Student Experiment – alternative version

If you have access to datalogging equipment, this is a good opportunity to get students to set up and record results automatically.

If a pc projector is available it is worth collecting one set of data to use at the end of the practical session (you could generate this yourself or else harvest a reliable set from one of the students/groups).

TAP 109-2: Electrical characteristics – Datalogging alternative

Discussion:

The results

In either case it is useful to bring the class together at the end of the practical session (say, 15 minutes before the end of the lesson) to discuss results. If you have collected some sample data you can show them how to process this in real time using Excel and a PC projector. Use this to instruct them about trend lines (don't join the dots and don't let Excel take over!). For some or all it may be worthwhile to recommend plotting by hand.

This may be the first time they have plotted graphs in Physics that include points in more than one quadrant, so this can be illustrated and discussed. Use terms such as 'ohmic' and 'non-ohmic' and encourage them to do the same. Reinforce the idea that an ohmic conductor is distinguished by a straight-line graph that passes through the origin. Remind them that resistance is the ratio of V to I not the gradient of the graph (particularly important when discussing the filament lamp).

Student questions:

On characteristics

Students will get confused between V against I and I against V graphs. Both will be encountered so they should be prepared.

TAP 109-3: Lamp and resistor in series

TAP 109-4: Using non-ohmic behaviour

TAP 109- 1: Electrical characteristics

Introduction

In this set of activities you are going to find out about the way circuit components conduct electricity.

A potential difference maintained across a conductor drives a current through that conductor. You will measure the size of the current for different applied potential differences and plot the results on a graph. The behaviour of the conductor as shown by an I – V graph is called its characteristic.

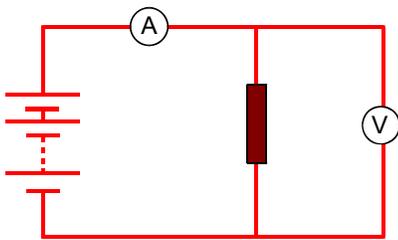
Apparatus

- ✓ 100 Ω carbon film resistor 1 W or even 0.5 W
- ✓ filament lamp 12 V, 24 W SBC (6 V 300 mA MES might be more convenient)
- ✓ diode – 1N4001 (NB: max current 1 A) with a protective resistor $\sim 50 \Omega$ or greater
- ✓ clip component holder
- ✓ 4 mm leads
- ✓ heatproof mat
- ✓ 2 multimeters
- ✓ power supply, 0–12 V d.c. (continuously variable if possible)
- ✓ rheostat (e.g. 50 Ω 1W) only needed if power supply has stepped output

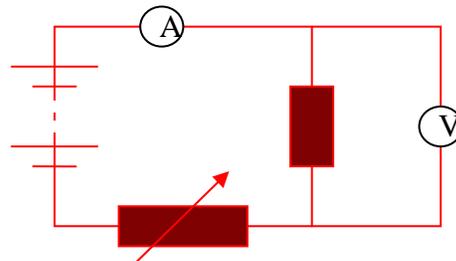
Experiment 1: Carbon film

1. Mount the carbon resistor in the clip holder.
2. Set up the basic circuit. Connect up the ammeter and resistor in series with the variable power supply. Place a heatproof mat under the resistor, although you should not let the resistor get too hot. Switch off the supply or disconnect the resistor when not making a measurement!
3. Connect a voltmeter in parallel with the resistor. You will need to select a range that will measure up to 5 V. At this stage your teacher may wish to check your circuit for you.
- 4.

If power supply continuously variable:



If power supply stepped output:



5. Switch on the circuit and adjust the supply so that the voltmeter reads 4 V. Quickly note the ammeter reading and voltmeter readings. Switch off for a few seconds, to prevent the

Plot a graph

Label the x-axis as 'potential difference / V' and the y-axis as 'current / A'. When the resistor is reversed you can show that the potential difference and the current are reversed by using a negative sign.

When you have finished plotting your results draw a best-fit line through the points.

A straight line graph through the origin shows that the current is proportional to the potential difference. This result is known as Ohm's law, which applies to metal or metal-like wires as long as their temperature remains constant.

For any point on the graph the resistance R can be found by calculating V/I . If the graph is a straight line then the resistance is constant – the same for every value of current or potential difference. Under these conditions finding the $1/\text{gradient}$ gives the average resistance of the wire. (Graphs using best-fit lines are often the best way of averaging results.)

The resistance is the same in both directions.

Further experiments

Experiment 2: Filament bulb

Set up the basic circuit but using the bulb in a holder instead of the carbon resistor.

This time the bulb can be left on between measurements. Repeat/check readings can be obtained by repeating the whole experiment but you will need to take care to reproduce (exactly) the voltage reading across the bulb.

Experiment 3: Semiconductor diode

Wire up the basic circuit substituting the diode. There must be a protective resistor in series with the diode to prevent damage by too large a current.

The diode is a one-way device and you may find that you cannot record a current as you increase the voltage up to 4 V. In this case reverse the diode in the holder. If in doubt ask your teacher.

Even in forward bias (conducting), the current through the diode will be very small so you may find the ammeter is not sensitive enough to show the change in current. Use a milliammeter or a digital multimeter set to read current but make sure the range of the milliammeter is greater than the maximum current through the diode.

Repeat/check readings can be obtained by repeating the whole experiment but you will need to take care to reproduce (exactly) the voltage reading across the diode.

If you want to explore the reverse bias of the diode you will need to use a microammeter to measure the tiny current.

Graphs for experiments 2–3

Either draw graphs with four quadrants choosing appropriate scales, or enter data on a spreadsheet and produce one or more appropriate graphs. Make the graph look as good as you can, to communicate its message as clearly as possible.

Give each one a caption which expresses the message of the graph. What is it saying?

Is the component well described by Ohm's law?

Remember that the filament of the lamp is designed to run white hot. At high temperatures metals conduct less well than at low temperatures.

Practical advice

Where you start on this activity depends on the experience and confidence of your students. The characteristics of the wire/resistor and the filament lamp are now part of many pre-16 specifications.

You can divide the further experiments up amongst groups of students. Each group can then produce the graph, research the behaviour of the component to explain the characteristic and then give a presentation to the rest of the class. Photocopies of the graphs can be distributed to members of the class.

Encourage students to use the higher range from a meter, selecting more sensitive ranges when they have an estimate for the highest reading. Digital meters are more robust, easier to read and even the 0–10 A scale is reasonably sensitive. If you do have to use moving coil instruments you will need to check that the meter is correctly inserted in the circuit and the range is suitable.

Experimental data and graphs on I / V characteristics of a filament lamp, a neon lamp and a silicon diode are on the CD-ROM Advancing Physics.

Technician's note: the specified ranges are indications only. It may be necessary to run through the experiment yourself to make sure your components and meter ranges are compatible.

Alternative approaches

These experiments can be easily adapted for datalogging and the graphs drawn automatically by the software, e.g. Insight.

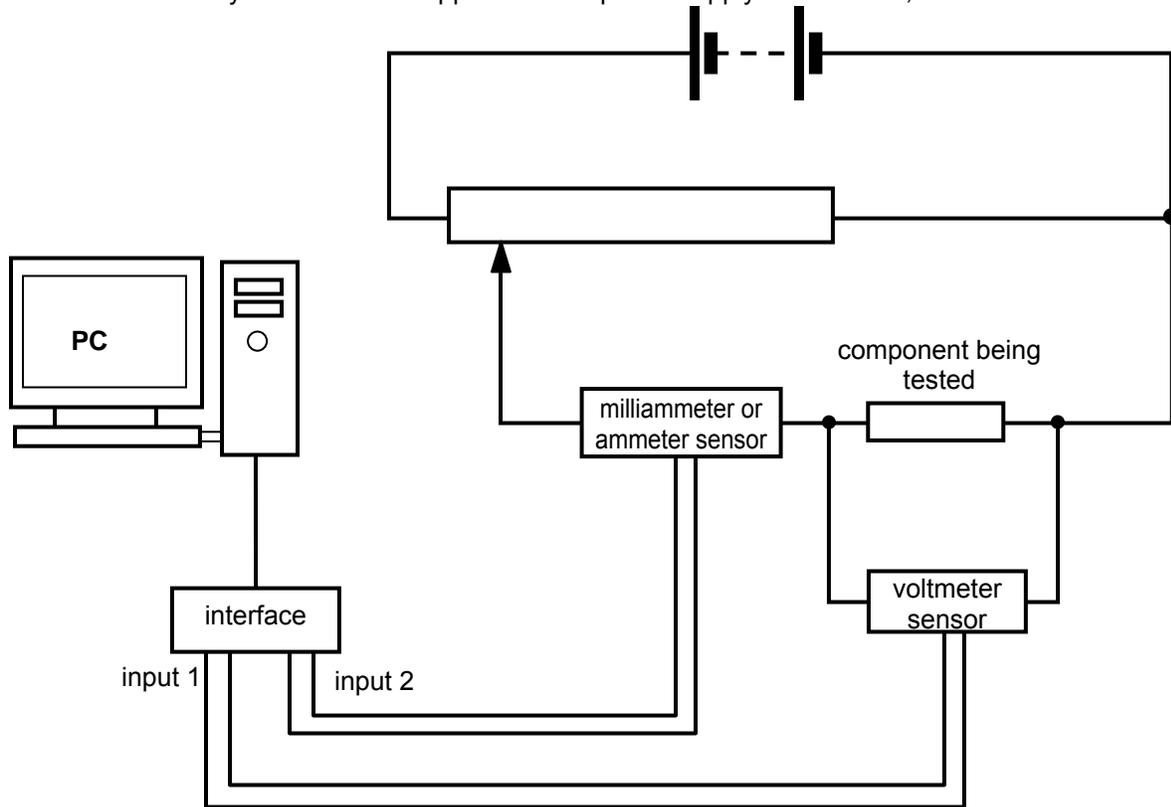
Similarly results obtained manually can be keyed into a spreadsheet package such as Excel or Insight and the graphs obtained. These spreadsheets will give an analysis of the shape of the graph.

External references

This activity is taken from Advancing Physics, Chapter 2, 150E

TAP 109- 2: Electrical characteristics - datalogging alternative

The details of the set-up will depend on the types of sensors that your school uses. Sensors may not automatically remove mains ripple from the power supply. In this case, use either batteries or



a smooth stabilised power supply designed for electronics work.

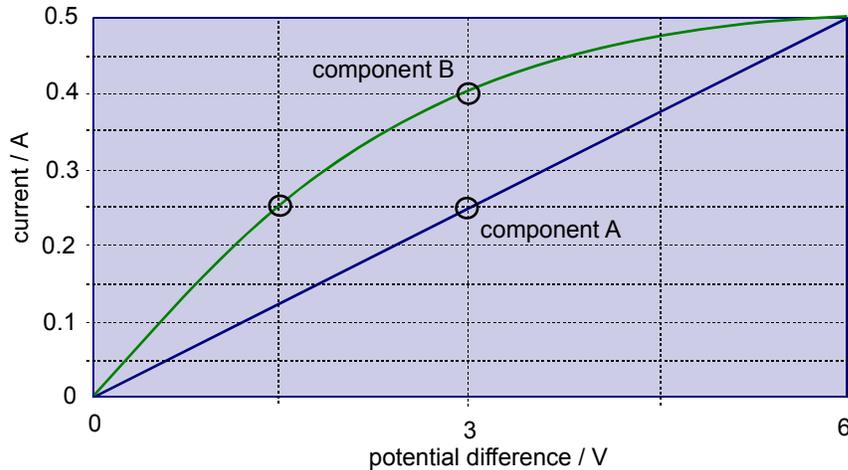
The basic arrangement is shown above. Results can be taken simply by sliding the contact along the rheostat - with a suitable software package this will draw a graph of I against V in real time. Reversing the component has the effect of changing the sign of both I and V , providing data for 'reverse bias' conditions. If this method is used with the filament lamp, care must be taken to get reliable results. The high sampling rates of most dataloggers means that the current and voltage can be recorded before the filament itself reaches an equilibrium temperature. To get the expected curve for the filament lamp it is important that the rheostat is adjusted slowly. Alternatively it should be possible to take discrete readings rather than sampling continuously. This allows the current to be adjusted and temperature equilibrium to be reached before anything is measured.

An interesting extension experiment or demonstration is to monitor the current through the filament lamp as it is switched on. This shows an initial surge (while the filament is relatively cool and therefore has lower resistance) and a gradual reduction to a steady value (at constant high temperature). Be sure to check the inherent response time of the sensor however, or you could be measuring an artificial effect only!

This diagram illustrates the generic set-up for a data-logging experiment. Note that, for some systems, only voltage sensors are provided so you can convert them to current sensors by putting them in parallel with $1\ \Omega$ resistors.

TAP 109- 3: Lamp and resistor in series

Study the characteristics of the two electrical components A and B shown.



1. What is the resistance of each component with a potential difference of 3 V across it?
2. Suggest what each component could be.

The two components are connected in series across a variable d.c. supply. A high resistance digital voltmeter measures the pd across A.

3. What is the current through A when the voltmeter reads 3 V?
4. What is the potential difference being provided by the supply?
5. If the supply potential difference is increased so that the voltmeter reads 6 V, what is the power being dissipated in each component?

Hints

1. Read the currents flowing with a potential difference of 3 V
3. Read the current from the graph.
4. Read the pd across B at a current equal to that through A; add the pd to that across A.
5. Find the current in A from the graph; find the pd across B for this current from the graph; use $P = I V$

Answers and worked solutions

1. $A = 12 \Omega$; $B = 7.5 \Omega$
2. A is an ohmic resistor, perhaps a metal wire. The resistance of B increases with current. It could be a filament lamp.
3. 0.25 A

4. 4.5 V
5. 3 W

External references

This activity is taken from Advancing Physics, Chapter 2, 190D

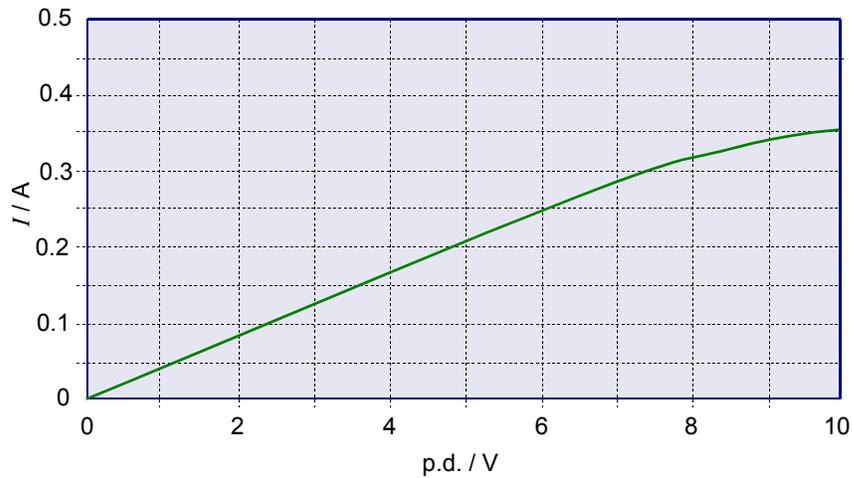
TAP 109- 4: Using non-ohmic behaviour

Instructions:

Using a diode for meter protection

The graphs show the characteristics of (i) a resistor made from a coiled wire and (ii) a commonly-used diode (forward bias).

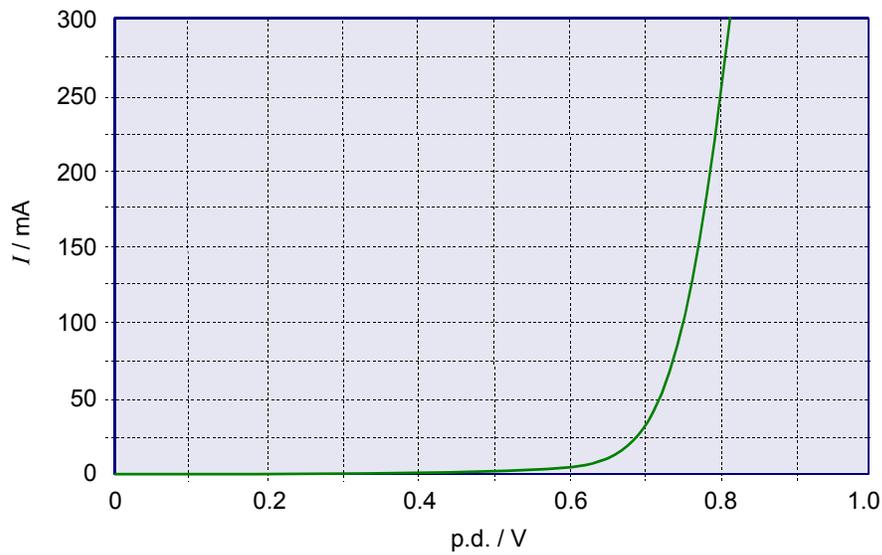
1. Current - p.d. characteristic for wire coil



Use the characteristic for a wire coil.

1. Describe and account for the shape of the graph.
2. What is the resistance of the coil in the ohmic region?
3. Estimate the maximum power rating of this resistance coil.

2. Current - p.d. characteristic for diode

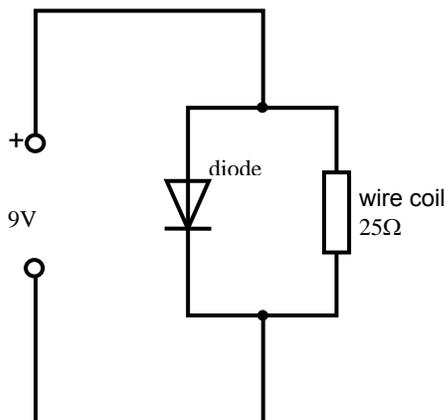


Use the characteristic for a diode

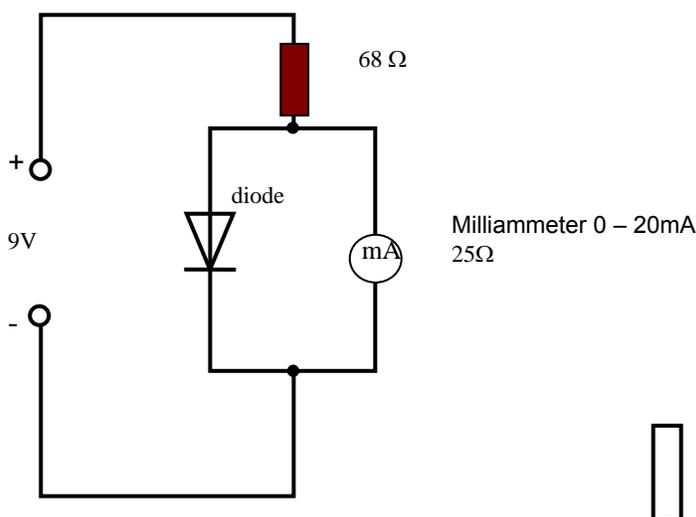
4. Describe and account for the shape of this graph.
5. Complete the table, using data from the graph to estimate the resistance of the diode in forward bias, at different values of the potential difference.

Applied pd / V	0.50	0.55	0.60	0.65	0.70	0.75	0.80
Resistance / Ω							

The diode and the coil are connected in parallel across a variable d.c. source.



6. Copy the characteristic of the coil in the range 0 to 0.8 V onto this diode characteristic. Using a different colour draw a new curve to show how the total current supplied to the coil increases as the applied pd increases from 0 to 0.8 V.



Some meters can be damaged if the current through them far exceeds the full scale current. A school physics technician is worried that the students may damage the milliammeters which they have been given to use in a circuit with a 68 Ω resistor. These meters have a full scale deflection of 20 mA; they have a resistance of 25 Ω, and similar characteristics to those in the graph above.

The technician solders a diode in parallel with each meter.

7. Explain how this modification will protect the milliammeter.

Practical advice

This question can follow activities on electrical characteristics. It gives practice at graph reading and graph plotting.

If students have only used digital meters it would be good to show them a moving coil meter, to see how it could be damaged by excessive current.

Hints

1. When the applied pd exceeds 8 V, the coil starts to get hot.
6. You will need to calculate or estimate the equivalent resistance of the parallel combination for some applied pds.

Worked solutions

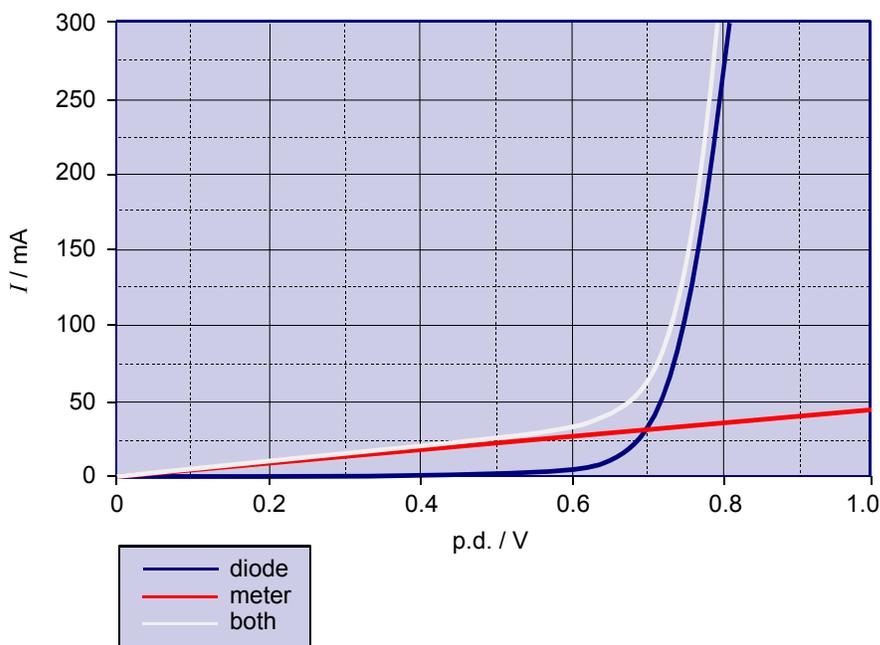
- Current proportional to pd up to about 7 V – metals follow Ohm's law. Above 8 V the resistance is increasing because the current is heating up the coil.
- 2.5 Ω
- 2.5 W approx.
- The diode does not conduct until the applied pd exceeds 0.6 V (the threshold). It is not an ohmic device. The current increases faster than the applied pd (because the number of charge carriers increases).

5.

Applied pd / V	0.50	0.55	0.60	0.65	0.70	0.75	0.80
Resistance / Ω	>1000	550	200	65	23	7.5	2.8

6.

3. Currents in the meter and the diode



- When the unprotected milliammeter reads 20 mA, the pd across it ($V = IR$) must be 0.5 V. When the milliammeter is protected, the resistance of the diode is too large in comparison with the coil's resistance to affect the circuit and carry any significant current.

If the circuit current rises to about 25 mA, the pd across the meter exceeds 0.6 V. The diode in parallel will become conducting at that applied pd and divert some of the current away from the coil. The student's graph shows that if the current through the combination rises much higher, most of the current flows through the diode; the meter will not be damaged by high current. However, the current cannot rise indefinitely since the 68 Ω resistor limits the circuit current to 175 mA.

External references

This activity is taken from Advancing Physics, Chapter 2, 270D